Vibration / Resonance	Vibration Problem of Straightening Plate for Steam Reheater	Plant

Object Machine

Steam reheater containing a set of equipment for separation of moisture contained in steam and for reheating the steam within the same vessel between the high pressure and low pressure turbines of a power station (Fig.1). At the inlet, temperature is about 180ºC, pressure about 1MPa, and moisture about 12%. Straightening plates having two stage-flow passages are installed in order to guide the inflow steam to the steam ejection opening at the inlet.

Observed Phenomena

After one month from commencement of operation of the equipment, abnormal sound was confirmed in the equipment during the constant operation of rated thermal output. By Internal inspection after the plant shutdown, identified a large crack at the welding points on both sides of the intermediate plate of the straightening plates as shown in Fig.2.

Cause Estimation

By inspection and investigation, fault was found in the welding points and striation was observed on the fracture face. High speed steam flew into the inlet of the straightening plates in the obliquely downward direction, and a high cycle excitation force due to separation vortex occurring from the leading edge of the straightening plates was amplified by an air column resonance, which acted on the plates to cause vibrations, resulting in weld cracks.

Analysis and Data Processing

As shown in Fig.3, natural frequencies of the straightening plates are: 158Hz for the primary and 174Hz for the secondary. In the primary, the intermediate plate and the bottom plate are of the reverse phase, while in the secondary, they are of the same phase, which agree fairly well with the measurements. As for the excitation force acting on the straightening plates, a numerical flow analysis was conducted using an a LES (Large Eddy Simulation) model. Actually, a two-dimensional analysis was conducted with the boundary conditions shown in Fig.4 in order to shorten the calculation time. From the time history waveforms of differential pressure on both sides of the plate, power spectrum densities (PSD) in Fig.5 were calculated, together with the effectuation of frequency response analysis using a model in Fig.3. Based on the vibrations and amplitudes analyzed by giving the pressure PSD to the intermediate and the bottom plates, a detailed model including defective welds was used for analysis, whose result proved that the welds exceeded the fatigue limit.
Then, after the welds in question were adequately reinforced, these portions were not damaged. However, during subsequent operations, cracks appeared on other welded parts of the straightening plates, while reheaters of the same design on other sites did not experience this sort of problem. Therefore, in order to investigate the root cause, a 1/3 size similar model of the entire equipment was fabricated, to which air containing mist simulating the steam moisture was blown using a blower (about 3kPa), so as to measure the pressure at each part of the straightening plates.
Fig.6 shows the power spectrum density of differential pressure between the top and the bottom surfaces of the bottom plate. Applying the mist increases the value of PSD, while PSD had the same value for three different mist particle sizes. An acoustic analysis using the boundary element method shown in Fig.7 confirmed that a peak around 330 Hz was caused by an air column resonance, while a peak at 500 Hz was due to pressures changes caused by– natural vibration of the straightening plates. Frequency characteristic f' of the pressure PSD and pressure PSD' of the actual equipment are given by the following calculation:

$$f'=f_0(L_0/L')(V'/V_0),\ PSD'=PSD_0(\rho'/\rho_0)^2(V'/V_0)^4(f_0/f')=PSD_0(\rho'/\rho_0)^2(V'/V_0)^3(L'/L_0)$$

Experimental fluid density ρ_0=1.22kg/m3 (actual equipment ρ'=5.67kg/m3), typical speed V_0=50m/s (actual equipment V'=60m/s), scale ratio (L'/L_0=3). Thus, for Fig. 6, the frequency axis of the actual equipment shall be 0.4 times, while the PSD' axis 112 times. In case of air column resonance, V is equal to sound speed, sound speed in the air V_0=350m/s, sound speed in steam V'=502m/s, so that the frequency shall be 0.48 times. The air column resonance frequency at 330Hz in Fig.7 was 158Hz for the actual equipment, which is fairly equal to the 1st natural frequency in Fig.3. PSD of the actual equipment converted by the similarity rule are indicated in Fig.8. Values of random excitation components due to vortex are small and similar to those obtained by the first result of LES. Straightening plates of other sites are different in size (w:483, L:1751; w:383, L:1826) from this case, thus the natural frequency and the air column resonance frequency are apart from each other. It is thus estimated that no problem occurred.

Countermeasures and Results

Width of the straightening plates was modified from 394mm to 305mm, and plate thickness from 6mm to 8mm. The resultant natural frequency increased substantially from 158Hz to 308Hz. At the time of periodic inspection one year after resuming operation, no trouble such as weld cracks was identified.

Lesson

During the design stage, almost no examination was made on these straightening plates. In the case that a fluid collides at the edge of an enclosed space, it is preconditions that there is the possible occurrence of an excitation force due to air column resonance in addition to random loading caused by separation vortex. As estimation of load is difficult, but it is necessary to obtain frequencies of the random loading of the separation vortex by analysis so as to avoid possible resonance with the natural frequency of the structures.

References

Arihara, Okada, “Study on vibration response of guide plates subjected to fluid force”, D&D 2009, 550-1 - 6”, 2009

Keyword

Flow-induced vibration, air column resonance, random excitation, straightening plate, separation vortex, numerical fluid analysis, model experiment, similarity rule

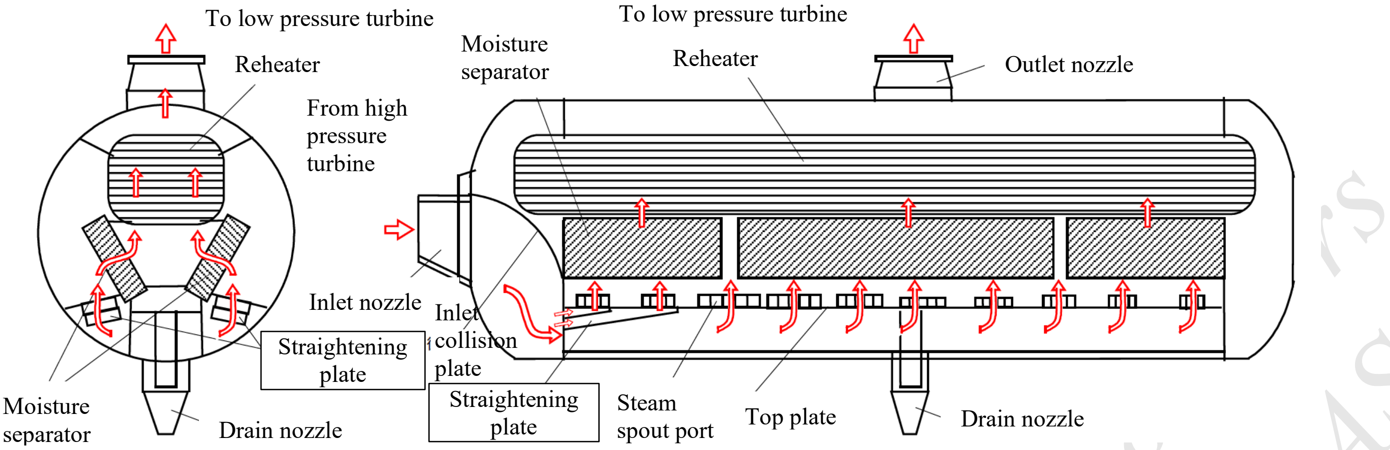

Fig.1 Steam reheater (total length: about 12m, diameter of cylindrical shell: about 3.2m)

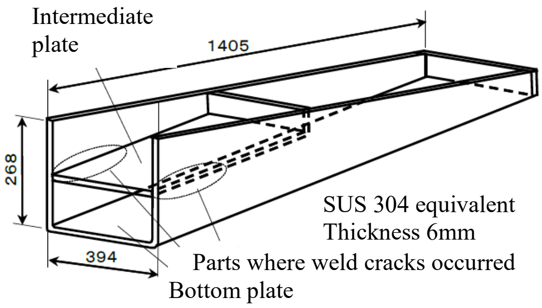

Fig.2 Straightening plate and parts where weld cracks occurred

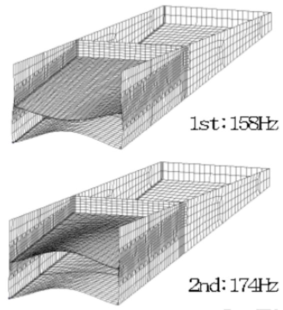

Fig.3 Natural frequency of straightening plate

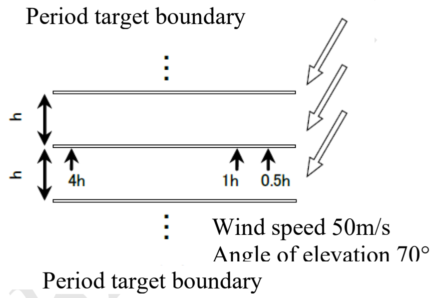

Fig.4 Fluid numerical analysis model

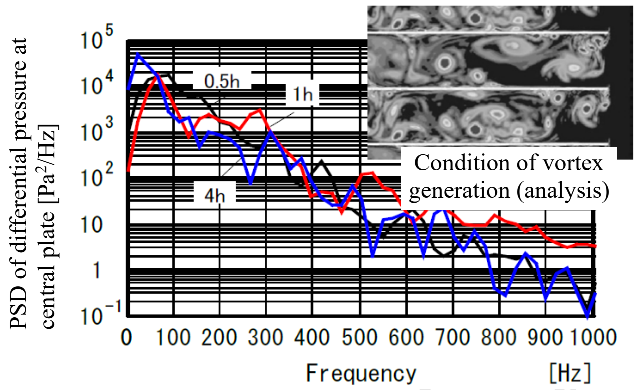

Fig.5 PSD of intermediate plate differential pressure by LES calculation

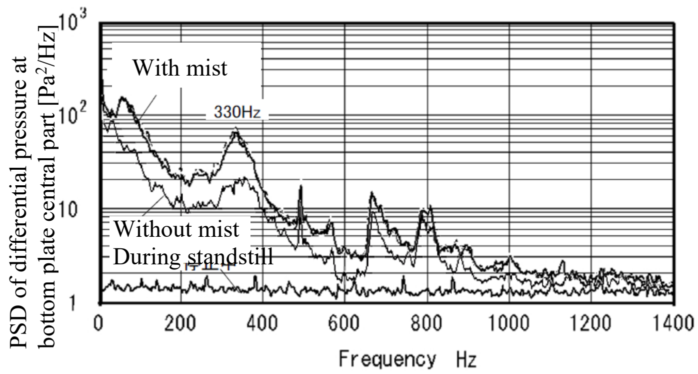

Fig.6 Differential pressure PSD of bottom plate central part by 1/3 scale model test

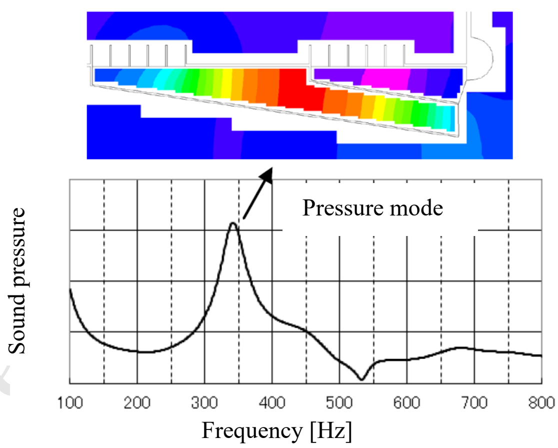

Fig.7 Acoustic calculation result of straightening plate by boundary element method

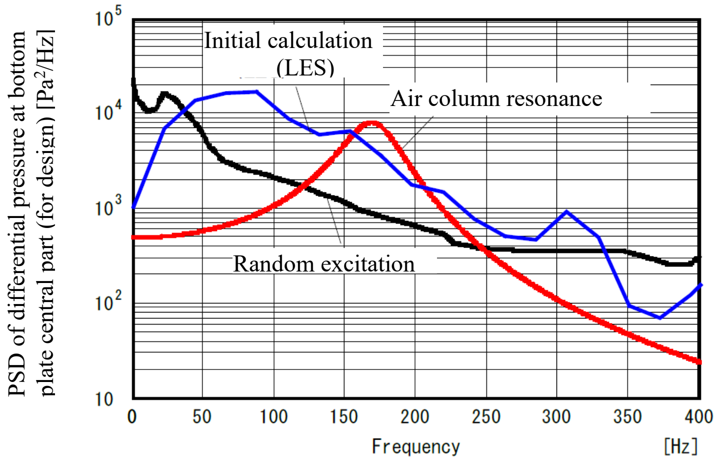

Fig.8 PSD for design of air column resonance and random excitation component (bottom plate central part)